

POLYMER COATINGS FOR CHEMICAL SENSORS

BACKGROUND OF THE INVENTION

This invention relates to use of polymeric films in sensors.

Mass-sensitive sensors have varying configurations. Typically, a sensor is provided with a chemically sensitive film that is applied onto a surface of the sensor, for example onto the surface of the sensor's crystal. Interactions of the film with a material to be detected, for example an analyte, induce a change in at least one of the mass and visco-elastic properties of the film. This change is measured as a shift of the resonance frequency of the sensor's crystal and is related to the concentration of the analyte. For detection of analytes of differing nature, the coating and analyte interactions include, but are not limited to, hydrogen bonding, π -stacking, acid-base, electrostatic and size/shape recognition.

The sensor's configuration, materials, and other characteristics vary to define operational characteristics, resonance frequencies, and boundaries for the sensor. For example, differing piezoelectric materials for a sensor substrate operate differently, and thus define the sensor's operational boundaries and characteristics. Therefore, if a sensor comprises a quartz crystal microbalance (QCM) as a sensor substrate, the sensor operates by propagating mechanical oscillations generally perpendicularly between parallel faces of a thin, quartz-crystal piezoelectric element. If a sensor comprises a surface acoustic wave (SAW) device as a sensor substrate, mechanical oscillations are propagated in substantially up-and-down undulations at a radio frequency (RF) along the surface of a thin, quartz-crystal piezoelectric element.

The chemically sensitive film permits the sensor to more readily detect a target analyte or other compound (hereinafter "target compound"), which is not ordinarily sensed by the sensor. The sensitive film often comprises a polymeric material film (hereinafter "polymeric film"), which changes the response of the sensor by altering the sensor's mechanical oscillation frequencies, and thus permitting the

target compound to be detected by the sensor. The sensor's changing frequencies result from the polymeric film's interaction with the target compound. Accordingly, various target compounds can be detected by a sensor when the nature of reaction between the polymeric film and target compound is known.

5 The target compound, usually a vapor, is dissolved (absorbed) into the film, by a process known in the art as "partitioning." A partition coefficient, K , is a thermodynamic parameter that corresponds to an equilibrium distribution of sorbed molecules between the gas phase and polymeric film. The partition coefficient is ratio of a concentration of target compound in the polymeric film, C_F , to the concentration of the target compound outside of the film, C_V . The partition coefficient K is determined according to Equation (1)

$$K = C_F/C_V \quad (\text{Equation 1})$$

15 One example of such an altered frequency results from a changed polymeric film mass. An increased film mass lowers a frequency at which the crystal oscillates, including for which it oscillates when exposed to a target compound. Thus, the target compound perturbs the oscillation of the sensor when the mass of the polymeric film increases, and thus the target compound can be detected. The oscillation frequency and mass change of a polymeric film often necessitate that it be thin and mechanically rigid. The thin nature of a polymeric film is needed so that the polymeric film's visco-elastic properties, and any changes in those visco-elastic properties produced by partitioning of the target compound thereto, do not adversely influence the oscillations of the sensor and provide inaccurate detection of a target compound. Further, the polymeric film should be mechanically rigid so the sensor provided with the polymeric film can have repeated sensing applications.

25 SAW sensor devices coated with thin polymeric material film (known in the art as "chemosensors") have been used as micro-sensors for detecting vapors. The sensitivity to a specific vapor (target compound) for such a SAW chemosensor depends on the type, physical and chemical properties, and materials of polymeric film. For example, each of a polymer-vapor partition coefficient, rate of absorption,

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and desorption processes influence the operational characteristics of a polymeric film. Examples of materials for polymeric films used as on a SAW chemosensor include, but are not limited to, phenyl-methyl-polysiloxanes, poly(epichlorohydrin), poly(isobutylene), poly(ethylene maleate), and poly(ethylenimine). Some of these materials do not provide stable operations in which controlled, accurate, reliable, and repeated detections are possible. Although SAW sensors are more sensitive than QCM sensors, the relatively low partition coefficients of polymers used in the past preclude the use of SAW and QCM sensors for detection of low concentrations of analytes.

10 A sensor with polymeric film that provides capabilities for determination of low concentrations of analytes (also known as target compounds) is needed. The polymeric film should also provide a long term stability of operation for reliable detection results.

SUMMARY OF THE INVENTION

15 A sensor comprises a substrate and a polymeric film disposed on the substrate. The polymeric film comprises at least one hardblock component and at least one softblock component.

20 The invention also sets forth a method for enhancing detection of a target compound by a sensor. The method comprises disposing a polymeric film on a surface of the sensor, in which the polymeric film enhances detection of target compounds not normally sensed by a sensor without the polymeric film. The polymeric film comprises at least one hardblock component and at least one softblock component.

25 A polymeric film for a sensor is further set forth by the invention. The polymeric film comprises at least one hardblock component and at least one softblock component.

These and other aspects, advantages and salient features of the invention will become apparent from the following detailed description, which, when taken in conjunction with the annexed drawings, where like parts are designated by like reference characters throughout the drawings, disclose embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a calibration curve for the determination of toluene with polymer-coated QCM sensors at 20°C with a polymeric film comprising BPA-PC-Silicone 81% DMS "BPASI";

Figure 2 is a calibration curve for the determination of toluene with polymer-coated QCM sensors at 20°C with a polymeric film comprising BPA-PC-Silicone 50% DMS "XD-7";

Figure 3 is a calibration curve for the determination of toluene with polymer-coated QCM sensors at 20°C with a polymeric film comprising Hytrel 3078;

Figure 4 is a calibration curve for the determination of toluene with polymer-coated QCM sensors at 20°C with a polymeric film comprising Lomod J613;

Figure 5 is a calibration curve for the determination of toluene with polymer-coated QCM sensors at 20°C with a polymeric film comprising Siltem 2000;

Figure 6 is a calibration curve for the determination of TCE with polymer-coated QCM sensors at 20°C with a polymeric film comprising BPA-PC-Silicone 81% DMS "BPASI";

Figure 7 is a calibration curve for the determination of TCE with polymer-coated QCM sensors at 20°C with a polymeric film comprising BPA-PC-Silicone 50% DMS "XD-7";

Figure 8 is a calibration curve for the determination of TCE with polymer-coated QCM sensors at 20°C with a polymeric film comprising Hytrel 3078;

Figure 9 is a calibration curve for the determination of TCE with polymer-coated QCM sensors at 20°C with a polymeric film comprising Lomod J613;

5 Figure 10 is a calibration curve for the determination of TCE with polymer-coated QCM sensors at 20°C with a polymeric film comprising Siltem 2000;

Figure 11 is a calibration curve for the determination of sub-ppmv levels of TCE with QCM sensors at 20°C coated with Siltem 2000 polymer films of different thickness, as indicated;

10 Figure 12 is a calibration curve for the determination of sub-ppmv levels of TCE with QCM sensors at 20°C coated with Siltem G15/40 polymer films of different thickness, as indicated;

Figure ¹³~~14~~ is a graph of log K, partition coefficient, of Siltem 2000 coated chemical sensors as a function of TCE concentration;

15 Figure ¹⁴~~15~~ is a graph illustrating the dynamic response of Siltem-coated chemical sensors, Siltem 2000 film thickness 41 kHz, to step changes in TCE concentration at 20°C, in which the numbers on the graph indicate TCE concentrations in ppmv at each step; and

20 Figure ¹⁵~~16~~ is a graph illustrating the dynamic response of Siltem-coated chemical sensors, Siltem G15/40 film thickness 48 kHz, to step changes in TCE concentration at 20°C, in which the numbers on the graph indicate TCE concentrations in ppmv at each step.

DESCRIPTION OF THE INVENTION

Sensors, as embodied by the invention, comprise polymeric films disposed on a surface of the sensor, in which the sensor is used to detect a target compound. The polymeric films, as embodied by the invention, comprise polymers that include hardblock and softblock polymers, such as thermoplastic elastomers. The polymeric film is disposed as a polymeric film coating on a surface of a sensor's piezoelectric crystal, and can be applied by accepted coating techniques.

A sensor, as embodied by the invention, comprises any appropriate sensor and sensor substrate, such as, but not limited to, acoustic wave sensors that include but are not limited to, quartz crystal microbalance (QCM) sensors, and surface acoustic wave (SAW) chemical sensors. These sensors are chemical sensors and find use in many diverse detection applications. The applications include monitoring in which it is desirable to detect various target compounds.

A polymeric film provides a sensor with an enhanced ability to detect some target compounds, for example hydrocarbon and chlorinated hydrocarbon vapors. These target compounds are not typically detected by certain sensors because they result in no or undetectable oscillations in the sensor, as these sensors typically function in the gravimetric range, meaning that the sensor's response is essentially mass sensitive. The enhanced ability to detect some target compounds is believed to be due, at least in part, to increased polymer-vapor affinity between the target compound and the sensor equipped with the polymeric film. The enhanced polymer-vapor affinity results in an increased measurement sensitivity. The enhanced measurement sensitivity for changed oscillation frequencies is typically about 1 part in about 10^8 . Therefore, measurement sensitivities for oscillation frequencies are not significantly affected by plasticization and associated visco-elastistic variation of the polymeric film.

The polymeric films, which include hardblock and softblock polymer base structures, exhibit reduced swelling and plasticization, compared to known films,

upon exposure to target compounds, including, but not limited to, hydrocarbon and chlorinated hydrocarbon vapors. Accordingly, a sensor provided with a polymeric film does not exhibit the swelling of prior polymeric film-equipped sensors.

5 The polymeric film comprises at least one polymer selected from polyester elastomer, polyether block polyamides, silicone polyimides, and combinations thereof. Each of these polymers includes, but is not limited to, softblock and hardblock components. Polymers that comprises a hardblock and softblock base structure comprise repeating high-melting blocks that are the hardblock components capable of crystallization, and amorphous softblock components that
10 possess a relatively low glass transition temperature. Examples of hardblock and softblock polymeric materials are set forth in US Patent Nos. 5,595,586 and 5,391,300, the entire contents of which are incorporated herein by reference. US Patent No. 5,595,586 teaches a method to sorb and desorb volatile organic compounds (VOCs), such as trichloroethylene (TCE), from air using softblock and hardblock
15 polymers.

The hardblock and softblock components of the polymeric film partition the target compound into the polymeric film, for example hydrocarbon vapor, as it enters the polymeric film. The hardblock and softblock components of the polymeric film are believed to provide structural integrity to the polymeric film. The
20 hardblock and softblock components are also believed to reduce swelling of the polymeric films' polymer and its associated effects, when the polymeric film is exposed to hydrocarbon vapors. Further, the hardblock and softblock components are believed to enhance surface adhesion of the polymeric film to a surface of the sensor's piezoelectric crystal. The enhanced surface adhesion is desirable for extended sensor
25 life for repeated absorption and desorption cycle applications.

One polymeric film, which includes a polyester elastomer, comprises hardblock and softblock components. An exemplary softblock component comprises polyoxyalkylene diimide diacids, and an exemplary hardblock component comprises

polyalkylene terephthalate. These materials are commercially available as HYTREL™ resins from DuPont and LOMOD™ resins from General Electric Company.

Another polymeric film, as embodied by the invention, comprises polyether block polyamides. The polyether block polyamides comprise polyether softblock components and polyamide (nylon hardblock) components. These materials are commercially available from Atochem, Inc. as PEBAX™ resins.

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A further polymeric film, as embodied by the invention, comprises silicone polyimides (sometimes referred to as "silicone polyetherimides"). Silicone polyimides comprise hardblock and softblock elastomer materials. Silicone polyimides are known in the art and are described, for example, in U.S. Pat. Nos. 4,808,686 and 4,690,997.

An example of a polymeric film on a sensor, as embodied by the invention, will now be discussed. A quartz crystal microbalance (QCM) sensor is provided with an AT-cut quartz crystal as a sensor substrate with gold (Au) electrodes. The crystal typically oscillates in a thickness-shear mode with a fundamental frequency of about 10 MHz. A polymeric film, as embodied by the invention, is disposed on a surface of the sensor. The film is disposed by appropriate processes, including but not limited to, is achieved by dip coating, spin coating, spray coating, vapor deposition, laser-assisted deposition, and other known methods.

The sensor will exhibit a changed oscillation frequency due to mass changes when contacted with material, for example a vapor, that includes the target compound. The mass increase of the sensor and the quartz crystal occurs through a solubility interaction between the polymeric film and vapor, which includes the target compound. This interaction produces a frequency shift (or change) of oscillations at the resonance frequency. Therefore, the change in oscillation frequency that is attributed to the target compound can be accurately detected.

Polymeric films, as embodied by the invention, comprise sorbent materials. The sorbent materials, as embodied by the invention, comprise polymers

with a single or several closely related repeating structural units. The repeating structural units are functionalized with groups to enhance selectivity and sensitivity of the sensor sorb target compounds. Using appropriate repeating structural units that are functionalized with appropriate groups, different target compounds can be detected. A glass transition temperature of the sorbent materials is lower and higher than operating temperatures for the first (soft) and the second (hard) structural polymer units, respectively. Further, different repeating structural units that are functionalized with such groups can be used in sensor arrays, so as to detect a plurality of target compounds.

The partition coefficient K is described above. The partition coefficient K thermodynamic parameter corresponds to an equilibrium distribution of sorbed molecules between the gas phase and polymeric film. The partition coefficient K is determined by Equation (1). A larger partition coefficient corresponds to an enhanced signal change for a sensor. The partition coefficient is determined in accordance with Equation (1):

$$K = C_F / C_V \quad (\text{Equation 1})$$

where C_F is a concentration of target compound in the polymeric film and C_V is the concentration of a target compound outside of the film.

If a density of the film ρ_F , a change in resonant frequency upon film deposition Δf_F , a concentration of the target compound C in the vapor, and a partition coefficient K of the film are known, a response for a acoustic wave sensor Δf_v can be determined in accordance with Equation (2):

$$\Delta f_v = (\Delta f_F C_V K) / \rho_F \quad \text{Equation (2)}$$

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Materials used as polymeric films, as embodied by the invention, are listed in Table 1. The Table also lists a reference material, polyisobutylene, that provides an indication of the effectiveness of polymeric films, as embodied by the invention. Table 1 also lists logs of partition coefficients (K) for polymeric films for toluene and TCE. Partition coefficients are presented as mean \pm SD, n=4, for the concentration range from 32 to 105 part per million in the vapor phase (ppmv) of toluene and from 33 to 110 ppmv of TCE, except of (*) which are presented for 0.1 ppmv of TCE.

Materials listed in Table 1 were used for fabrication of polymeric films on the QCM sensors for quantification of varying concentrations of toluene and TCE. Calibration curves for these polymeric films on sensors are presented in Figs. 1-10. All calibration curves with the polymeric films are generally linear over the investigated concentration range of analytes, with the exception of Siltem materials.

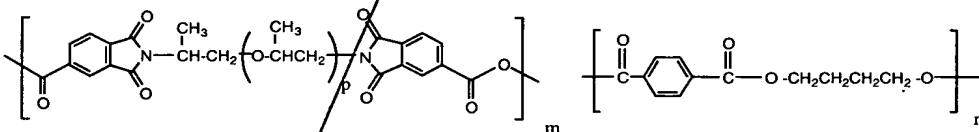
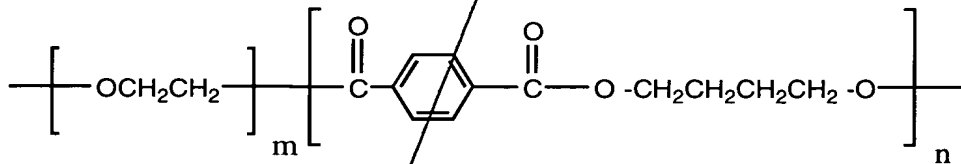
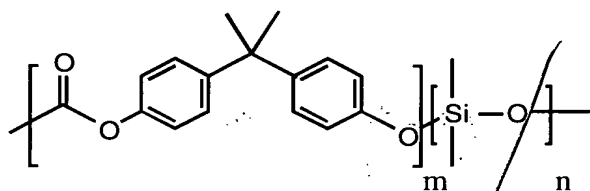
Trace levels of target compounds (analytes) can be detected with Siltem materials. For example, calibration curves for determination of sub-ppmv levels of TCE with QCM sensors at 20°C coated with polymers of different thickness are presented in Figs. 11 and 12. This capability is achieved due to the drastically enhanced partition coefficient of Siltem materials for low analyte concentrations. Figure 13 illustrates a logarithmic dependence of the partition coefficients of Siltem on concentration of TCE vapor. Similar dependence is observed for toluene.

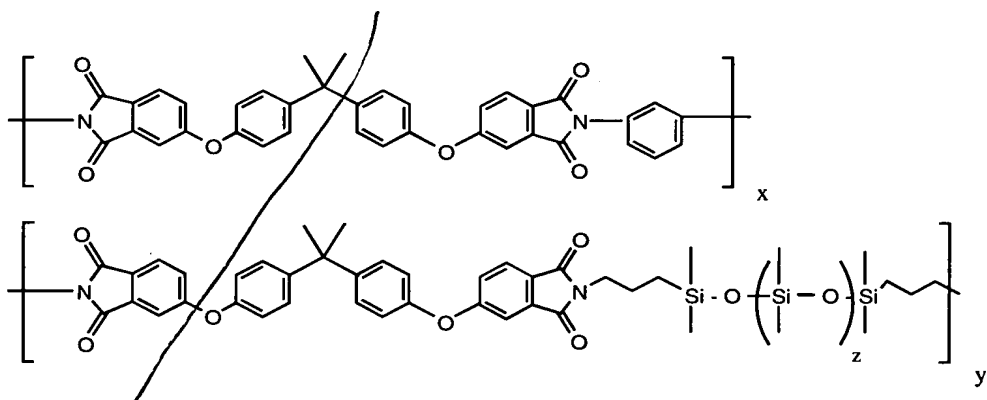
The materials, as embodied by the invention, when applied as polymeric films for chemical sensors, provide a reversible sensor response upon sequential exposure of coated sensors to analyte vapors and blank gas. A reversible sensor response means that the ability of the sensor is able to return to an original value, as illustrated about a 0.0 TCE concentration after a certain number of runs or after a certain temperature has been reached. Figures 14 and 15 illustrate the reversible response of polymer-coated QCMs to step changes in trichloroethylene concentrations in nitrogen.

Table 1

| Material | log Ktoluene | KTCE |
|---------------------------------|-----------------|------------------|
| BPA-PC-Silicone 81% DMS "BPASI" | 2.95 ± 0.04 | 2.76 ± 0.01 |
| BPA-PC-Silicone 50% DMS "XD-7" | 3.32 ± 0.03 | 3.07 ± 0.04 |
| Hytrel TM 3078 | 3.35 ± 0.02 | 3.09 ± 0.02 |
| Lomod TM J613 | 3.28 ± 0.02 | 3.03 ± 0.02 |
| Siltem TM 2000 | 4.0 ± 0.1 | 3.9 ± 0.1 |
| Siltem TM G15/40 | - | $5.33 \pm .06^*$ |
| Polyisobutylene** | 3.08 ± 0.02 | $5.44 \pm .03^*$ |
| ** - reference material. | | |

The following are chemical formulae for the materials used as polymeric films, as embodied by the invention.



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While various embodiments are described herein, it will be appreciated from the specification that various combinations of elements, variations or improvements therein may be made by those skilled in the art, and are within the scope of the invention.